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(54) Catalyst composition for alkene oligomerisation and co-oligomerisation.

(57) A catalyst composition comprising a first component which is a substituted-bis(cyclopentadienyl) titanium, zirconium or hafnium compound, also containing a substituent which is attached to the metal and which is capable of reacting with a cation and a second component which is a compound having a bulky and labile anion which is substantially non-coordinating under the reaction conditions and a cation, wherein each of the two cyclopentadienyl radicals is differently substituted by from 1 to 5 hydrocarbon substituents, none of which is attached to the metal, the total number of substituents being from 2 to 9.

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This invention relates to a novel catalyst composition and to its use in the oligomerisation and co-oligomerisation of one or more alkenes, in particular alpha alkenes. More in particular, the invention relates to the oligomerisation and co-oligomerisation of ethene.

Polymerisation processes of olefins, including alkenes, such as the production of polyethylene from ethene, whereby soluble catalyst systems of the Ziegler-Natta type are used, are well known. In particular, oligomerisation processes of lower olefins to higher olefins are also well known. For example, from GB-A-1353873 it is known that C<sub>4</sub>-C<sub>20</sub> linear alpha olefins can be prepared from ethene by oligomerisation in the presence of a nickel containing catalyst. The product linear alpha olefins, in particular those having 6-10 carbon atoms, are in great demand as intermediates in the preparation of detergents, lubricant additives and polyolefins.

However, the oligomerisation reaction also produces less valuable products, such as internal olefins and branched olefins and olefins having a number of carbon atoms outside the range of 6-24. By further processing, these by-products can be converted to the desired linear alpha olefins.

EP-A-0277003 and EP-A-0277004 both disclose catalyst compositions for the polymerisation and copolymerisation of olefins, comprising a combination of a first component which is a bis(cyclopentadienyl)-titanium, zirconium or hafnium compound containing a substituent which is attached to the metal and which is capable of reacting with a cation, and a second component which is a compound having a bulky and labile anion which is substantially non-coordinating under the reaction conditions and a cation, capable of donating a proton. The two cyclopentadienyl groups may be substituted. The products according to these documents are true polymers, having a molecular weight of above 100000 (when determined in the Examples). Consequently, no attention is payed to properties which are important to olefins having a number of carbon atoms of less than 30, such as linearity and the position of the double bond.

The present Applicant's EP-A-0443686 and non-prepublished European Patent Application 92202331.2 both disclose methods for the co-oligomerisation of ethene with at least one other alpha olefin in the presence of a catalyst composition as broadly described above, wherein one or both of the cyclopentadienyl groups may be substituted. The preferred and only exemplified substituted ligand pair is bis-pentamethylcyclopentadienyl. The product oligomers still contain a substantial proportion of the less valuable branched olefins and internal olefins.

It has now been found that catalyst compositions as described above, wherein each of the two cyclopentadienyl radicals is differently substituted by from 1-5 hydrocarbon substituents, none of which is attached to the metal, the total number of substituents being from 2 to 9, are particularly useful in the oligomerisation or co-oligomerisation of ethene and other lower alkenes to higher alkenes, in that they affect a more preferential production of the linear alpha alkenes of the range having 4-24 carbon atoms and more in particular 6-10 carbon atoms.

Accordingly, the present invention provides a catalyst composition comprising

- a first component which is a substituted-bis(cyclopentadienyl)titanium, zirconium or hafnium compound, also containing a substituent which is attached to the metal and which is capable of reacting with a cation and
- a second component which is a compound having a bulky and labile anion which is substantially non-coordinating under the reaction conditions and a cation,

characterized in that each of the two cyclopentadienyl radicals is differently substituted by from 1 to 5 hydrocarbon substituents, none of which is attached to the metal, the total number of substituents being from 2 to 9.

Preferably, the total number of substituents is from 4 to 8.

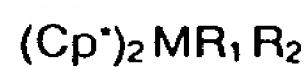
More preferably, one of the two cyclopentadienyl radicals is mono-substituted and the other cyclopentadienyl radical is penta-substituted.

Preferably, at least one of the two cyclopentadienyl radicals contains at least one substituent which is not present on the other cyclopentadienyl radical.

The catalyst composition may be formed prior to its introduction to the reaction vessel, or it may be formed in situ.

The invention also provides the use of this catalyst composition in an oligomerisation or co-oligomerisation process, in particular in a process for the preparation of linear alpha alkenes having 4-24 carbon atoms by oligomerisation or co-oligomerisation of ethene and/or an alpha alkene having 3-10 carbon atoms.

The first component of the catalyst composition according to the invention is preferably a compound of the general formula



wherein  $(Cp^*)_2$  is a bis-cyclopentadienyl ligand pair which is differently substituted as broadly described hereinbefore, M is a metal chosen from the group of titanium, zirconium or hafnium and R<sub>1</sub> and R<sub>2</sub> are identical or different and selected from unsubstituted or substituted hydrocarbyl groups, hydrogen and halogen.

- 5 Preferably, R<sub>1</sub> and R<sub>2</sub> are alkyl groups, typically of from 1 to 5 carbon atoms, such as methyl.  
The hydrocarbon substituents on the cyclopentadienyl radicals are preferably selected from the group of unsubstituted or substituted alkyls having 1-10 carbon atoms, more preferably those chosen from:  
Methyl, ethyl, iso-propyl, tert-butyl, cyclohexyl, adamantyl, phenyl, ortho-tolyl, para-tolyl, 2,5-dimethyl-phenyl, 2-tert-butylphenyl, 2,5-di-tert-butylphenyl and mesityl.

- 10 Preferred substituted bis-cyclopentadienyl ligand pairs are:  
(pentamethylcyclopentadienyl)(methylcyclopentadienyl), (pentamethylcyclopentadienyl)-  
(ethylcyclopentadienyl), (pentamethylcyclopentadienyl)(iso-propylcyclopentadienyl), (pentamethylcyclopentadienyl)(tert-butylcyclopentadienyl), (pentamethylcyclopentadienyl)(cyclohexylcyclopentadienyl), (pentamethylcyclopentadienyl)(adamantylcyclopentadienyl), (pentamethylcyclopentadienyl)-  
15 (phenylcyclopentadienyl), (pentamethylcyclopentadienyl)(ortho-tolylcyclopentadienyl), (pentamethylcyclopentadienyl)(para-tolylcyclopentadienyl), (pentamethylcyclopentadienyl)(2,5-dimethylphenylcyclopentadienyl), (pentamethylcyclopentadienyl)(2-tert-butylphenylcyclopentadienyl), (pentamethylcyclopentadienyl)(2,5-di-tert-butylphenylcyclopentadienyl), and (pentamethylcyclopentadienyl)-  
(mesitylcyclopentadienyl). Preferred metals are zirconium or hafnium.

- 20 Such complexes can be prepared for example by the routes described in "Chemistry of Organo-Zirconium and Hafnium Compounds", by Lappert et al., 1986, published by John Wiley & Sons, Chichester, England.

The second component of the catalyst composition according to the invention is preferably an ionic combination of a bulky anion containing a plurality of boron atoms and a proton-donating cation, the anion being such that it is substantially non-coordinating under the reaction conditions employed. Thus, it is intended that the anion should not coordinate, or at least coordinate only weakly, to the bis-(cyclopentadienyl) metal entity of the first component. The boron-containing non-coordinating anion is preferably a carborane anion, suitably a carborane anion of the formula B<sub>11</sub>CH<sub>12</sub><sup>-</sup>. Such carboranes are known and can be prepared by methods such as that of Shelly et al, J. Am. Chem. Soc. 107 (1985) 5955-5959. Other bulky boron containing anions may also be used, such as a tetra(perfluorophenyl) boron anion. The proton-donating cation is preferably a quaternary ammonium cation such as a trialkylammonium cation, for example tri-n-butylammonium cation. Alternatively a cation may be used which is not proton-donating, such as a metal cation e.g. a silver ion, or a triphenylcarbenium ion.

The catalyst composition may be formed by mixing together the two components, preferably in solution in a suitable solvent such as toluene, chlorobenzene, an alkane or an alkene, to form a liquid catalyst system. The two components are generally employed in substantially equimolar amounts, although the molar ratio of the first component to the second component may vary within the range of from 0.1 to 5.0. Such a quantity of the catalyst system is usually employed in the reaction mixture as to contain from 10<sup>-1</sup> to 10<sup>-7</sup> gram atoms, in particular from 10<sup>-3</sup> to 10<sup>-5</sup> gram atoms, of the metal per mole of olefin to be reacted.

The oligomerisation reaction according to the invention can be carried out in batch or continuous operation.

The oligomerisation reaction is generally, although not necessarily, carried out in an inert liquid which is suitably also the solvent for the catalyst components. The reaction is suitably carried out at an elevated temperature, preferably in the range of from 20 to 175 °C, more preferably at 50 to 150 °C. The reaction is suitably carried out under conditions of moderately elevated pressure, preferably in the range of from 100 to 10000 kPa, more preferably from 500 to 6000 kPa. The optimum conditions of temperature and pressure used in a particular reaction system in order to maximise the yield of the desired linear alpha alkenes can be readily established by those skilled in the art, but it has been found that conditions of between 70-90 °C and between 4000-6000 kPa are particularly advantageous in this respect with the catalyst systems of the present invention.

The starting reactants may be supplied to the reactor together with an inert diluent, such as nitrogen or helium when the reactant is gaseous, and a liquid solvent, e.g. the same solvent as that of the catalyst components, when the reactant is in the liquid form.

55 The reaction is preferably carried out in the absence of air or moisture.

Reaction times of from 1 minute to 5 hours have been found to be suitable, depending on the activity of the catalyst system and on the reaction conditions. After a suitable reaction time, a conventional catalyst deactivating agent such as water, methanol, or another alcohol, may be added if desired to the reaction

mixture in order to terminate the reaction. Alternatively, the reaction can simply be terminated by the introduction of air.

The product mixed alkenes are preferentially linear alpha alkenes having a chain length within the range of 5 to 24 carbon atoms, of which those having between 6 and 10 carbon atoms in the chain are particularly preferred. They may be suitably recovered by distillation and separation techniques known in the art. If desired, unconverted starting material and oligomeric products having a molecular weight outside the desired molecular weight may be recovered, processed if necessary and recycled to be used as starting material in a subsequent oligomerisation reaction.

The invention will be further illustrated by the following examples.

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#### Examples 1 to 7

The procedures were carried out with rigorous exclusion of oxygen and moisture.

Catalyst liquors were prepared by dissolving in toluene, as First Component, in 30 ml, 0.25 mmol of

- (Cp\*)<sub>2</sub>MR<sub>2</sub>, wherein M is zirconium, R<sub>2</sub> is dimethyl and (Cp\*)<sub>2</sub> is:
  - in comparative Example 1: bis-pentamethylcyclopentadienyl;
  - in comparative Example 2: bis-methylcyclopentadienyl;
  - in comparative Example 3: bis-iso-propylcyclopentadienyl;
  - in comparative Example 4: bis-tert-butylcyclopentadienyl;
  - in Example 5: (pentamethylcyclopentadienyl)(methylcyclopentadienyl);
  - in Example 6: (pentamethylcyclopentadienyl)(iso-propylcyclopentadienyl);
  - in Example 7: (pentamethylcyclopentadienyl)(tert-butylcyclopentadienyl);
- and as Second Component, in 70 ml, in all cases 0.05 mmol of Bu<sub>3</sub>NHB<sub>11</sub>CH<sub>12</sub> (tri-n-butylammonium 1-carbadodecarborate).

The Second Component of the catalytic composition was first added to an autoclave of 500 ml, followed by pressurising the autoclave with ethene to 1000 kPa, and heating to 90 °C.

Subsequently, the reaction was started by adding the First Component of the catalytic composition. Pressure was maintained at 1000 kPa during the reaction by continuously recharging of consumed ethene.

At the end of the (predetermined) reaction time, the reaction was terminated by water injection. The product distribution was determined by gas-liquid chromatography.

The amount of ethene consumed during the reaction, the amounts of C<sub>4</sub>, C<sub>6</sub>-C<sub>10</sub> and C<sub>12+</sub> olefins produced, and the wt% distribution of alpha-, beta- and branched hexene are given in Table 1.

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TABLE 1

Example	1	2	3	4	5	6	7
<b>Reaction time</b>							
(min)	3	103	70	150	25	26	20
<b>Ethene consumed</b>							
(g)	25	25	25	25	25	25	25
<b>Product C<sub>4</sub></b>							
olefin (g)	0.9	2.0	4.0	22.4	2.2	6.0	17.8
<b>Product C<sub>6-10</sub></b>							
olefins (g)	3.8	7.0	10.8	2.6	7.5	12.5	7.1
hexene (g)	1.1	2.3	4.1	2.4	2.5	5.3	5.3
<b>Product C<sub>12+</sub></b>							
olefins (g)	20.3	16.0	10.2	0.0	15.3	6.6	0.1
<b>Distribution of hexenes (wt%)</b>							
1-hexene	81.8	57.9	61.2	44.3	96.6	95.9	89.1
2-hexene	17.6	39.4	36.6	15.4	3.0	3.2	1.9
2-ethyl-							
1-butene	0.7	2.7	2.2	40.3	0.4	0.9	9.0

Examples 8 to 10

The procedure was the same as that of Examples 1 to 7, except that,

- as First Component, 1 mmol (Example 8 and 9) or 0.25 mmol (Example 10) of (Cp\*)<sub>2</sub>MR<sub>2</sub> was used, wherein M is hafnium, R<sub>2</sub> is dimethyl and (Cp\*)<sub>2</sub> is:
  - in comparative Example 8: bis-pentamethylcyclopentadienyl;
  - in comparative Example 9: bis-tert-butylcyclopentadienyl;
  - in Example 10: (pentamethylcyclopentadienyl)(tert-butylcyclopentadienyl);
- as Second Component, 1 mmol (Example 8 and 9) or 0.1 mmol (Example 10) of Bu<sub>3</sub>NHB<sub>11</sub>CH<sub>12</sub> (tri-n-butylammonium 1-carbadodecacarborate) was used; and the total amount of toluene solvent in the autoclave was 270 ml (Example 8 and 9) or 70 ml (Example 10).

The amount of ethene consumed during the reaction, the amounts of C<sub>4</sub>, C<sub>6-C<sub>10</sub></sub> and C<sub>12+</sub> olefins produced, and the wt% distribution of alpha-, beta- and branched hexene are given in Table 2.

TABLE 2

Example	8	9	10
Reaction time (min)	2	30	30
Ethene consumed (g)	40	76	30
Product C <sub>4</sub> olefin (g)	1.6	72.2	23.4
Product C <sub>6-10</sub> olefins (g)	6.7	2.3	6.5
hexene (g)	2.0	2.2	5.3
Product C <sub>12+</sub> olefins (g)	31.7	1.5	0.1
Distribution of hexenes (wt%)			
1-hexene	23.6	22.6	76.2
2-hexene	75.9	2.4	0.8
2-ethyl-1-butene	0.5	75.0	23.0

Examples 11 to 13

The procedure was the same as that of comparative Examples 1 and 2 and Example 5, respectively, except that the First and Second Components of the catalyst composition were dissolved in 15 and 60 ml of toluene respectively and that, together with the Second Component, 210 mmol of 1-pentene (comonomer for reacting with the ethene) was injected into the autoclave.

The amount of ethene consumed during the reaction, the amounts of C<sub>4</sub>, C<sub>6+8+10</sub>, C<sub>7+9+11</sub> and C<sub>12+</sub> olefins produced, and the wt% distribution of alpha-, beta- and branched hexene and heptene are given in Table 3.

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TABLE 3

	Example	11	12	13
5	Reaction time (min)	4	150	38
10	Ethene consumed (g)	25	25	25
15	Product C <sub>4</sub> olefin (g)	0.2	0.8	2.5
20	Product C <sub>6+8+10</sub> olefins (g) hexene (g)	0.8 0.2	2.9 1.0	7.5 2.6
25	Product C <sub>7+9+11</sub> olefins (g) heptene (g)	4.5 1.4	2.7 1.0	3.8 1.4
30	Product C <sub>12+</sub> olefins (g)	24.5	21.6	15.2
	Distribution of hexenes (wt%)			
	1-hexene	89.8	60.3	96.9
	2-hexene	10.2	38.9	2.7
	2-ethyl-1-butene	0.0	0.8	0.4
	Distribution of heptenes (wt%)			
	1-heptene	86.3	57.6	93.1
	2-heptene	13.4	31.6	2.7
	2-ethyl-1-pentene	0.3	10.8	4.2

From these Examples it is apparent, that catalyst compositions according to the invention, when used in the oligomerisation of ethene (Examples 5-7 and 10) and in the co-oligomerisation of ethene and pentene (Example 13), have the advantage above comparative catalyst compositions of promoting the selectivity of the reaction towards linear alpha-olefin reaction products.

#### Claims

- 40 1. A catalyst composition comprising a first component which is a substituted-bis(cyclopentadienyl) titanium, zirconium or hafnium compound, also containing a substituent which is attached to the metal and which is capable of reacting with a cation and a second component which is a compound having a bulky and labile anion which is substantially non-coordinating under the reaction conditions and a cation,  
characterized in that each of the two cyclopentadienyl radicals is differently substituted by from 1 to 5 hydrocarbon substituents, none of which is attached to the metal, the total number of substituents being from 2 to 9.
- 50 2. A catalyst composition according to claim 1, characterized in that one of the two cyclopentadienyl radicals is mono-substituted and the other cyclopentadienyl radical is penta-substituted.
- 55 3. A catalyst composition according to claim 1 or 2, characterized in that least one of the two cyclopentadienyl radicals contains at least one substituent which is not present on the other cyclopentadienyl radical.
4. A catalyst composition according to any one of claims 1-3, characterized in that the first component of the catalyst is a compound of the general formula

$(Cp^*)_2MR_1R_2$

5 wherein  $(Cp^*)_2$  is a bis-cyclopentadienyl ligand pair which is differently substituted as broadly described hereinbefore, M is a metal chosen from the group of titanium, zirconium or hafnium and  $R_1$  and  $R_2$  are two identical or different groups selected from unsubstituted or substituted hydrocarbyl groups, alkyloxy groups, hydrogen or halogen.

10 5. A catalyst composition according to claim 4, characterized in that  $R_1$  and  $R_2$  are unsubstituted alkyl groups of from 1 to 5 carbon atoms.

15 6. A catalyst composition according to any one of claims 1-5, characterized in that the hydrocarbon substituents on the cyclopentadienyl radicals are chosen from the group of: unsubstituted or substituted alkyls or aryls having 1-10 carbon atoms, preferably from methyl, ethyl, iso-propyl, tert-butyl, cyclohexyl, adamanyl, phenyl, ortho-tolyl, para-tolyl, 2,5-dimethylphenyl, 2-tert-butylphenyl, 2,5-di-tert-butylphenyl and mesityl.

20 7. A catalyst composition according to any one of claims 1-6, characterized in that the substituted bis-cyclopentadienyl ligand pair is chosen from the group of:

(pentamethylcyclopentadienyl)(methylcyclopentadienyl), (pentamethylcyclopentadienyl)-  
(ethylcyclopentadienyl), (pentamethylcyclopentadienyl)(iso-propylcyclopentadienyl), (pentamethyl-  
cyclopentadienyl)(tert-butylcyclopentadienyl), (pentamethylcyclopentadienyl)-  
(cyclohexylcyclopentadienyl), (pentamethylcyclopentadienyl)(adamantylcyclopentadienyl), (pentamethyl-  
cyclopentadienyl)(phenylcyclopentadienyl), (pentamethylcyclopentadienyl)(ortho-tolylcyclopentadienyl),  
25 (pentamethylcyclopentadienyl)(para-tolylcyclopentadienyl), (pentamethylcyclopentadienyl)(2,5-dimethyl-  
phenylcyclopentadienyl), (pentamethylcyclopentadienyl)(2-tert-butylphenylcyclopentadienyl), (pen-  
tamethylcyclopentadienyl)(2,5-di-tert-butylphenylcyclopentadienyl), and (pentamethylcyclopentadienyl)-  
(mesitylcyclopentadienyl).

30 8. A catalyst composition according to any one of claims 1-7, characterized in that the second component of the catalyst is an ionic combination of a bulky anion containing a plurality of boron atoms which is substantially non-coordinating under the reaction conditions employed, with a cation.

35 9. A catalyst composition according to claim 8, characterized in that the boron-containing non-coordinating anion is a carborane anion.

10. A catalyst composition according to claim 9, characterized in that the carborane anion is of the formula  $B_{11}CH_{12}^-$ .

40 11. A catalyst composition according to any one of claims 8-10, characterized in that the cation is a proton-donating cation.

12. A catalyst composition according to claim 11, characterized in that the proton-donating cation is a quaternary ammonium cation.

45 13. A catalyst according to any one of claims 8-10, characterized in that the cation is a silver ion.

14. Use of a catalyst composition as claimed in any one of claims 1-13 in a process for the preparation of linear alpha alkenes having 4-24 carbon atoms by oligomerisation or co-oligomerisation of ethene and/or an alpha alkene having 3-10 carbon atoms.